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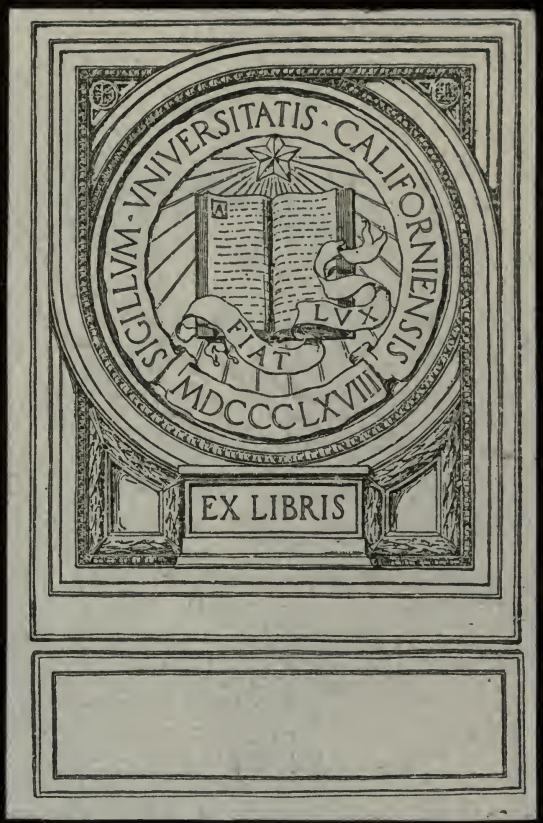
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UNDERGROUND WATERS
FOR
COMMERCIAL PURPOSES

BY

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INTRODUCTION

While much has been written upon the subject of waters, there has been no attempt to collect in one volume the material presented herein. The available published material has followed two rather sharply defined lines, one devoted to the consideration of waters from various sources for industrial purposes; the other devoted to discussion of waters for municipal and public uses.

The subject of underground waters for commercial purposes has received meagre attention at the hands of various writers, and it is the author's intention in the following pages to discuss in more or less detail this phase of the question. The rapidly growing population of our country, especially in the vicinity of our large cities, makes the question of a sufficient and safe water supply one of prime importance. The urban population will be compelled more and more in the future to look to sources other than the public supply for water for drinking and domestic use.

The bottled, or mineral, water trade of the United States has already reached large proportions, and is yet in its infancy. Only ten or fifteen years ago the

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man who had the temerity to suggest that bottled waters would find an extended market among any but the wealthy was looked upon as a visionary; yet it is only necessary to point to the fact that the value of mineral waters sold in the United States in 1911 was $6,837,888, in order to see that there are large possibilities in this line of commercial activity. There were seven hundred and thirty-two springs reporting sales in 1911 with a combined output of 63,923,119 gallons. This does not take into consideration the quantities of water supplied to guests at the various spring resorts, nor that used in the manufacture of so-called "soft drinks," such as pop, ginger ale, etc. Likewise, there were many springs which made no report, and their output could not be included in the foregoing estimate.

Many sources of information have been drawn upon in the preparation of this work, and while it is impracticable to acknowledge each citation, the appended bibliography covers practically all the authorities consulted, and to these the author wishes to express his obligations and thanks.

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CHAPTER I

SOURCE OF WATER

THE source of all underground water which rises in the form of springs or is obtained by sinking wells is the rain which falls upon the surface of the earth. A few exceptions to this statement are the hot springs found in various sections of the country, due to volcanic action, and a few inclusions of ocean water in sedimentary rocks. But these are small compared to the large number and wide distribution of non-thermal springs.

Springs whose source is the rainfall are found throughout the world, and vary in size from the tiniest rill to a stream large enough to carry steamboats. There are springs in Florida with a flow of over 360,000 gallons per minute, steamboats ascending the stream caused by their overflow to the very source. As certain geologic conditions are necessary to the formation of springs, they are oftentimes grouped in more or less restricted localities.

When rain descends upon the earth part of the water finds its way immediately into streams and lakes, constituting the run-off; part is absorbed by

growing plants, part enters into chemical reactions in the soil, and a certain amount is immediately returned to the air by evaporation. The remainder passes downward to various depths, to appear later in the form of springs, or in swamps and lakes. This portion of the rainfall is known as ground water. The run-off sooner or later reaches the larger bodies of water, where it evaporates and is again deposited upon the surface of the earth as rain or snow.

The portion of the rainfall constituting the ground water pursues a different course. It passes downward, due to the force of gravity, until, coming in contact with some obstruction, its course is directed more or less horizontally. Sooner or later it finds an outlet at the surface. In its passage through the ground this water may travel long distances, and may come in contact with soluble materials which will be carried along with it, completely altering its composition when it emerges; or it may reach the surface in the immediate vicinity in which it was deposited, having undergone little change in its passage. This is specially true in limestone regions where filtering agents are scarce and where the rain quickly finds its way into seams, joints, and fissures, following along these until it reaches the surface. Thus it can be seen readily why waters coming from different sections of the country have different composition; or,

waters from closely adjacent areas may have a wholly different composition, as the composition of underground strata have been found to be radically different in contiguous localities.

Rain, or meteoric, water is the purest form of natural water obtainable. It is closely related to distilled water; in fact, it is water that has been distilled by nature and condensed in the form of clouds. During a given rainfall the first water that descends washes the dust particles from the air, and is thus more or less contaminated. The remaining water is practically free from contamination, except for the small amount of gases it may absorb in its descent from the clouds. These conditions are modified by the surroundings, such as factories emitting smoke and gases and other sources of contamination.

The air in the vicinity of chemical factories is saturated to a greater or less degree with chlorine, nitrous oxid, various acids, etc., depending upon the particular form of manufacture carried on at that place. Smelter fumes contain large quantities of arsenic which may be carried miles by air currents, dwarfing the growth of all vegetable life in its path.

Vapors arising from decomposing vegetable matter in swamps and bogs contain gases which will be taken up by the rain in its descent and carried with it into the earth.

Snow acts in much the same way as does rain in its properties of purifying the atmosphere and absorbing gases. The bacterial content of snow is usually lower than that of rain, as the air in winter contains fewer bacteria than in summer.

It can thus be seen readily that the more thickly populated a country is the less likely the inhabitants are to obtain a satisfactory water supply in their immediate vicinity.

CHAPTER II

GROUND WATER

As previously noted, ground water is that portion of the rainfall which soaks into the ground to appear later as springs or wells. Rain water tends to pass downward, due to the force of gravity, but its passage is resisted by the earth particles between which it must pass. In sands and gravels where these spaces are numerous and relatively large, the water passes quite readily; in sandstones where the spaces are small, capillary attraction exerts a strong influence in retarding the movement of the water. In limestone and granite there is little or no movement in the rock mass itself due to the extreme fineness of these spaces, the resulting friction, and the effect of capillary attraction; but there is rapid and free movement of the water in fissures, joints, seams, and faults in this type of rock.

As soon as water comes in contact with the surface of the earth it is changed. Where before it had been practically pure, it is now contaminated by soil bacteria, and it also takes up various soluble elements present in the soil. If the water emerges in the

same vicinity in which it was deposited, it will have the characteristics of the soil in that vicinity; but if it travels some distance under the surface before it again finds an outlet, it may take on varying characteristics, depending upon the kind of geologic strata it has traversed.

In sandy and gravelly subsoil there are no distinct channels through which the water passes, but it finds its way between the grains of sand as best it may. The spaces between sand grains, whether the grains are loose or combined in sandstone, are called pores, and the relative size and abundance of these openings constitute the porosity of a given medium. Porosity is expressed as a percentage of the whole mass. Thus, if 100 cubic feet of rock will absorb 20 cubic feet of water, the porosity of that rock is 20 per cent. Rocks formed under water by sedimentation are the most porous.

The porosity of a rock or other medium is its power to absorb water. The ability to transmit, that is, to allow of the passage of water through a rock, is known as the permeability. This depends upon the amount and character of the porosity, large pores allowing water to pass through more rapidly than small pores, due to the decreased resistance. The presence of joints, fractures, seams, etc., in a rock also increases its permeability. Rocks may have a high porosity,

but slight permeability, due to the extreme fineness of the pores.

Permeability depends not alone upon the presence of pores in the rock, but also upon the communication of one pore with another. If the communicating channels are few and small the permeability will be very greatly reduced, and although the porosity of the rock may be high, its power to transmit water will be very slight. Under such conditions the presence of fissures and joints in the rock will greatly increase its transmitting power. The following table from Gregory (11) gives the limits of porosity of different water-bearing materials:

Rock	Per cent of Pore Space	Water absorbed per cu. ft. (qts.)
Sandstone	4.81	2–6
	28.28	
Limestone	.14	¼–1¼
	13.36	1–5
Marble	.184	
	3.578	
Granite	.969	1/100–¼
Slate	.099	
	.304	
Chalk		4–8
Sand		8–10
Clay		10–12

The figures given show the ordinary limits of the porosity of the rocks.

From the above table it is seen that clay has a high porosity, but its permeability is slight owing to the extremely small size of the pores, although their aggregate capacity is rather large.

The movement of water through the earth is quite slow, being measured in feet per year rather than miles per hour or day, as is the case with surface streams. Rate of movement is also dependent upon the pressure behind, and the inclination or grade along which it flows. Water tends to pass vertically downward, but obstructions of rock masses, slate, clay, or other materials, which are impenetrable may cause the formation of considerable head. According to Slichter (28), who bases his calculations upon experimental work, with a temperature of 50° F., a porosity of 32 per cent, and a pressure gradient of ten feet to the mile, water has been estimated to travel in a year in fine sand 52.8 feet; in medium sand, 216 feet; in coarse sand, 845 feet, and in fine gravel, 5,386 feet. This is through a medium of uniform composition.

An increase in temperature causes an increase in the rapidity of movement. At a temperature of 70° F. the rate of movement is double that at 32° F., because at the higher temperature the water is less viscous.

The temperature of ground water is the same as the mean temperature of the region under which it lies. The temperature of the outer crust of the earth to a thickness of about 50 feet is influenced by the seasonal variations in the climate. At a depth of 50 feet the temperature is practically constant and is the same as the mean temperature of that particular region. Below a depth of 50 feet the temperature increases one degree for each 60 feet in depth, on an average. Therefore it can be seen that, generally speaking, waters can be no colder than the mean temperature of their particular region. This is contrary to the general belief that water whose temperature is quite low in hot summer weather, or whose temperature does not vary throughout the year, must come from great depths. The farther below the outer zone of 50 feet from which waters rise, the higher will be their temperature.

Waters lying less than 50 feet below the surface are colder in winter and warmer in summer, as they are acted upon by external climatic conditions. On the other hand, waters coming from great depths have a temperature above the average for the region in which they occur, corresponding to the depth from which they rise. Waters reaching the surface as hot springs must come from deep sources, as many of them have a temperature of at least 180° F. at their point of emer-

gence, and must of necessity have lost some heat in rising to the surface.

Fuller (8) says: "Springs with a temperature of over 150° F. are rare, if they occur at all outside of igneous regions. As this temperature represents only a depth of 5,000 feet on the basis of an increment of 1° to each 50 feet of depth, it is readily seen that we have ordinarily no truly deep-seated springs whatever. Springs at the boiling point would represent a depth of only about 8,000 feet."

All water finally reaches a certain level beneath the surface of the earth, where it ceases to pass downward, and is directed in a horizontal plane, forming a more or less continuous bed of water. This is known as the ground-water table, and will be discussed more fully under the subject of springs. (Chapter IV.) This ground-water table underlies practically all the earth's surface, is tapped when wells are sunk, and also forms springs, lakes, and marshes when the surface of the earth is eroded, as in a valley or ravine, and the water-bearing stratum is cut across.

CHAPTER III

DISTRIBUTION AND PROPERTIES OF WATER

WATER is the most widely distributed substance of which we have knowledge. The hardest crystals and the driest rocks contain appreciable quantities of water. In fact, crystals could not form were it not for the action of water. The human body is composed largely of water, it being present in the various tissues in amounts varying from two per cent to ninety-nine per cent. A body weighing 165 pounds will be composed of 115 pounds of water. Plant life, like animal life, has a large amount of water in its composition.

Geographers tell us that three-fourths of the surface of the earth is covered with water, and the interior of the earth contains large quantities, as shown by the many thermal springs and geysers that exist in widely separated parts of the universe.

The amount of free water in the earth's crust has been estimated by Delesse (Fuller, 8) to be "equivalent to one nine-hundred-twenty-first part of the earth's volume, or to a sheet of water over 7,500 feet thick surrounding the earth." Slichter (28) calculates the amount as "being equivalent to a

uniform sheet 3,000 to 3,500 feet in thickness." Van Hise (32) furnishes an estimate that the water on continental areas would form a layer 226 feet deep, but makes no calculation regarding oceanic areas. Chamberlin and Salisbury (Fuller, 8) estimate that the amount of free water in the earth's crust would form a layer 1,600 feet in depth; and Fuller (8) has determined, after a careful and close study of all factors, that this figure should be reduced to 96 feet.

It has been estimated that no free water exists below a depth of about 20,000 feet beneath the land in crystalline rocks. It will be possible for free water to be found at a greater depth at points below the ocean. In sedimentary rocks little free water exists below 2,600 feet in depth.

Water is an odorless, tasteless, colorless liquid. A layer of water of some thickness may show a bluish tinge. It is neutral in reaction. It is the most universal solvent known, and for this reason is very hard to obtain in the pure state.

Absolutely pure water is never found in nature, and is difficult to obtain even in the laboratory. It is necessary to distil water twice, and to conduct the operation with special care, in order to get absolutely pure water.

The term pure water may have various meanings, depending upon the purpose for which it is to be used.

Water may be chemically pure when it contains no substances which would interfere with chemical reactions. It is bacteriologically pure when it contains no bacteria capable of setting up diseased conditions when taken into the system, regardless of its chemical composition. It is pure from a sanitary point of view when it contains no evidences of pollution from the wastes of man or animals; and it may be considered pure by the engineer when it contains no lime or salt to form boiler scale, or organic matter in sufficient amount to cause foaming. So we see that when a pure water is spoken of, its use, whether for chemical, bacteriological, sanitary, or industrial purposes, must be borne in mind.

Rain water, if obtained before reaching the surface of the earth, is the purest form of natural water, as is also snow. As soon as it has come in contact with the soil, however, it becomes contaminated, owing to its solvent action. Ice is also a very pure form of natural water, as most of the substances in solution are forced out into the surrounding water during the process of freezing. Water that is contaminated bacteriologically is purified to a great extent by the process of freezing, and ice that has been frozen for a few months is perfectly safe to use, even though its source was polluted.

A good descriptive term for a mineral water is

"potability." A potable water is one free from pollution, pleasing to the taste, and perfectly safe for drinking and domestic use. It may and should contain some chemical substances which give it a pleasing taste, and may contain bacteria, provided no organisms indicative of pollution are present. The combination of chemicals in a given water gives that water its individual taste. Distilled water, lacking these chemical salts, has a very flat and insipid taste, and in a soft water the same insipidity will be noted in a lesser degree, owing to the small amount of chemical salts in solution.

On the other hand, a water may hold such a large proportion of chemicals in solution as to be very disagreeable in taste. Large quantities of sodium chloride (common salt), magnesium sulphate (Epsom salts), various forms of iron, sulphur, and other chemical substances impart to water a characteristic and oftentimes disagreeable taste.

The taste of water, aside from extreme conditions, is largely a matter of personal preference. After drinking for some time water with a certain chemical content we become accustomed to it, and when a change is made to a water of different chemical content the altered taste is readily noticeable.

Certain properties of pure water are taken as standards in chemical and physical calculations. The

standard of specific gravity is based upon water, its specific gravity being 1 at 15° C. It is the standard of weight in the metric system, a cubic centimetre of water at 4° C. weighing one gram. Standards of heat are based upon water; the amount of heat required to raise one gram of water 1° C. is taken as the basis and is known as the calorie. Specific heat of other substances is given in comparison with this standard.

Chemically water is composed of but two elements, hydrogen and oxygen, in proportion of two parts of the former to one of the latter. Its formula is, therefore, H_2O. Water occurs in three physical states—viz.: solid, liquid, and gas, and can be transformed readily and easily from one to the other under the proper environment of temperature and pressure.

CHAPTER IV

SPRINGS

A SPRING is a stream of water emerging from the ground, its flow being due to definite, natural causes. By this definition many so-called "springs" are excluded, which are in reality only wells which have been sunk to the level of the water-bearing strata and the water lifted to the surface by means of various mechanical devices.

The flow of springs varies to a marked extent. Some may be of small volume, scarcely more than a rivulet, while others will be capable of carrying steam vessels. Some of the largest flowing springs are found in Florida, notable among these being the Silver Springs, with an estimated flow of 368,913 gallons per minute, and Blue Springs, with a flow of 349,166 gallons per minute. (Sellards, 26.)

The formation of springs is due to certain geologic conditions, chief of which are the composition and arrangement of the different layers of material which go to form the earth's crust. It would be impracticable to describe all the conditions which enter into the formation of the different types of springs found

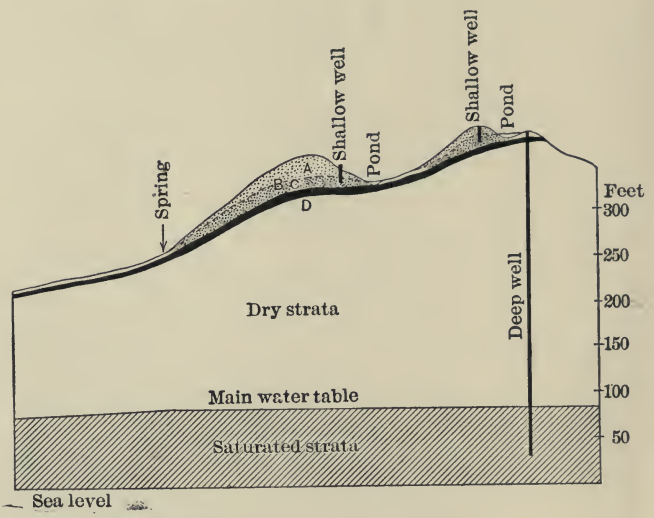
throughout the world, as an intimate knowledge of the geologic conditions in the vicinity of each would be necessary. There are, however, certain general principles which tend to the formation of springs, and which are as follows: First, a porous upper layer more or less saturated with water; second, an impervious layer immediately beneath the porous and lying in an inclined plane; third, the extension of these two layers to the surface of the earth.

Water falling upon the porous upper layer passes downward by the force of gravity until it comes in contact with the impervious layer. It will then be forced along the upper side of this layer, due to the pressure of the water behind, and finally emerge at the surface where the forces of weathering have eroded and exposed the non-porous layer. The body of water lying above this impervious layer is known as the ground-water table. Its position depends upon the deposition of the geologic strata beneath the earth's surface, also upon the amount of rainfall, being higher in a wet season than in a dry season.

There may be an impervious layer of rock or shale above the ground-water table at some particular point, but such a condition is more or less local, as the water has to find its way beneath the shale or clay at some point in the vicinity.

Occasionally one water table is found above an-

other. This is known as a "perched" water table. Such a table can occur only in hilly regions, and as its source of supply is restricted, it is affected readily by changes in the rainfall. Its formation may be better understood by reference to Fig. 1. A well sunk



Courtesy U. S. Geol. Survey.

FIG. 1. Perched Water Table. *A*, unsaturated strata; *B*. perched water table; *C*, saturated strata; *D* relatively impervious till.

only to the level of this perched table, or a spring supplied by it, will have a variable flow as compared with a well or spring supplied by the main ground-water

table situated beneath the intervening impervious stratum.

Fuller (10) classifies springs according to their origin as gravity and artesian; and according to the kind of passages traversed by the water, as seepage, tubular, and fissure springs.

A gravity spring is one whose source of supply is not confined between nonporous layers, but flows through the subsurface layers by gravity. It has no well-defined channels, the material through which the water flows being usually sand or gravel.

An artesian spring is one that emerges under hydrostatic pressure, due to the fact that its supply is confined between impervious layers and is higher at its source than at its point of emergence. If the waters of such a spring are confined in a pipe at the surface they will rise in that pipe some distance, depending upon the hydrostatic head.

Seepage springs are those in which the water seeps from the ground in a more or less restricted area. Their flow is seldom large, and in dry seasons may evaporate almost as fast as it reaches the surface. There is usually abundant vegetation around such springs, also scum and oily matter on their surface. This oil scum is frequently taken as an indication of oil deposits beneath the surface, but is in reality due to the decomposing vegetable matter or to iron. The

temperature of this class of springs is usually affected by climatic conditions, and they are not very cold. These springs belong to the gravity class.

Tubular springs include a variety of forms and are usually found in rocky, especially limestone, regions. The water feeding such springs flows through passages in the rock made by the solution of soluble substances, known as solution passages. They often follow porous strata such as sand and gravel inclusions in drift rock. They may find a channel left by some decaying vegetable matter and utilize it as a means of passage. In limestone regions such passages are often very long. Underground streams, such as that in Mammoth Cave, Kentucky, are known to extend for miles, and in all probability are of much greater length. As a general rule this type of spring belongs to the gravity class.

Fissure springs are those which rise from joints, seams, cleavage planes, or fissures in the rock. They are formed by the plane of the fissure cutting across the plane of flow of the underground water. They are usually of deeper origin than the seepage or tubular springs. Many of such springs may be found emerging in the same plane of fracture along the side of a hill, or along the edges of a ravine.

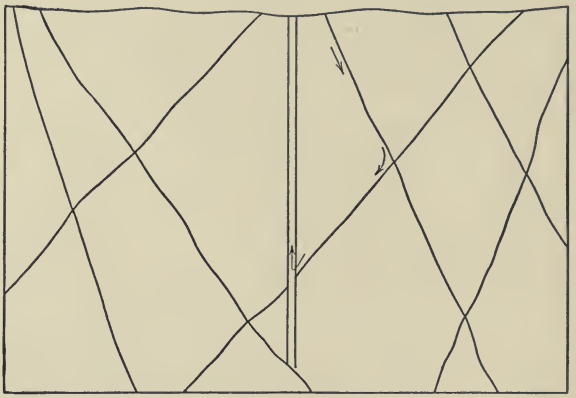
Springs which are found in mountainous and rocky regions are usually of the fissure type just described.

Here the water is not so well filtered as in sandy regions and likewise may travel for long distances with comparatively little filtration. About all the filtering such waters receive is that obtained by passing through the soil and subsoil; for as soon as the water reaches the rock proper it finds its way into the many crevices and joints of the rock mass and follows these to some outlet. Such springs are likely to be of uneven flow, as their source is more or less directly dependent upon the rainfall, and thereby directly influenced by it. They are also more likely to be contaminated, as the water has not had the chance to become purified by filtration, as is the case in sandy regions, but passes into the joints and fissures of the rock. Pollution is known to have been conveyed long distances by just such formations as have been described. Water from such springs is very likely to become turbid after a rain, due to the fact that more water passes through the soil at such times than can be filtered properly, and carries down with it particles of earth or rock matter in suspension.

Aside from joints and fissures which occur in limestone regions, large cavities are often formed which contain water, and which at times receive the discharge of streams, forming what are known as lost streams. This water with no filtration or purification may appear at some point further down as a flowing

spring, and will be grossly polluted by the material gathered by the lost stream earlier in its course.

The jointed and fissured formation of the rock in limestone regions may cause springs and wells to become contaminated from apparently impossible



Courtesy U. S. Geol. Survey.

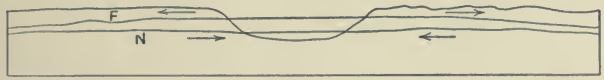
FIG. 2. Wells in jointed rocks.

sources. A well may be located on ground higher than and some distance from a polluting source as cesspool or barnyard; but the joints and fissures in the rock through which that well has been sunk, or which overlies the spring, may be such that polluting material can easily and quickly find its way from the surface to the water supply. (Fig. 2.)

Wells and springs located in limestone regions

should be examined most carefully both as to watershed and subsurface formations before they are used for drinking purposes.

An erroneous idea is prevalent in the minds of many people that a lake or stream even in remote proximity to a spring is the source of its supply, the water finding its way through the earth to the outlet. As a matter of fact most lakes and streams are fed by



Courtesy U. S. Geol. Survey.

FIG. 3. Movement of water away from and toward lakes. *N*, normal position of water table; *F*, position during floods.

the ground water, and the movement of this water is toward, rather than away from, such bodies of water. In times of heavy rainfall or other condition which will cause the normal level of the lake or river to rise, the movement of the ground water may be reversed, that is, it will be away from, rather than toward, the lake; but as soon as conditions are normal the movement of ground water will return to its normal course. (Fig. 3.)

CHAPTER V

WELLS

In contradistinction to springs, the supply of water drawn from wells does not reach the surface by its own effort, except in some artesian wells, but must be lifted by mechanical means. A well, therefore, is a tube of varying diameter sunk through the crust of the earth into the water-bearing strata and supplied with some mechanical arrangement for lifting the water to the surface.

The yield of a well depends on its depth, its topographic location, and the nature of the rock in which it is made. The deeper the well beyond a certain distance, the less likely is water to be found; especially is this true in regions composed of crystalline rocks. The pressure of the rock mass from above closes joints, seams and fissures, allowing little or no water to pass.

There are several types of wells known, among them being the dug, bored, drilled, punched, and driven. All these types may be used, depending upon the nature of the material through which the hole is sunk. In rocky regions a dug well would be difficult to sink, while in sandy sections it would be easily sunk, but

would need protection by shoring while the digging was in progress. Under these conditions a punched or drilled well in which the opening would be of a much smaller diameter, and in which the casing would be carried down with the drill, would be preferable.

Artesian wells are those in which the ground water rises toward or above the surface, due to hydrostatic pressure. "Gas as an agent in causing the water to rise is expressly excluded from the definition."

The word artesian is derived from Artois, an ancient province in France which was supplied with flowing wells. According to Matson (22) there are six conditions which usually produce artesian wells:

1. A porous bed or an open plane or channel to permit the entrance and passage of water.

2. An impervious cap to prevent the upward escape of the water.

3. An inclination of the water-bearing bed or passage.

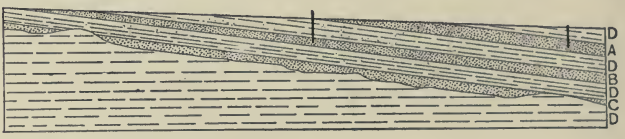
4. A suitable exposure of the water-bearing beds or passages above the level of the surface at the well to permit the entrance of the water.

5. An adequate rainfall to furnish the water.

6. An absence of openings which will permit the ready escape of water at a level below the well.

The disposition of geologic strata tends to the formation of artesian conditions, and may assume

various forms. The simplest form is that in which a porous saturated layer, such as sand, gravel, or sandstone, is situated between two impervious layers, the

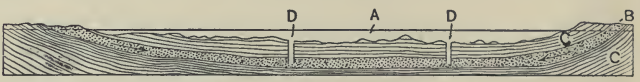


Courtesy U. S. Geol. Survey.

FIG. 4. Artesian slope. *A*, *B*, *C*, water-bearing strata confined between impervious strata *DD*.

whole mass being disposed in an inclined plane. When a well is sunk into this porous layer at a point below its source of supply the water will rise in the well toward or above the surface by means of the hydrostatic pressure under which it has been confined. This is known as an artesian slope, and may be better understood by reference to Fig. 4.

In an artesian basin we have a condition in which two slopes meet as one continuous formation, the



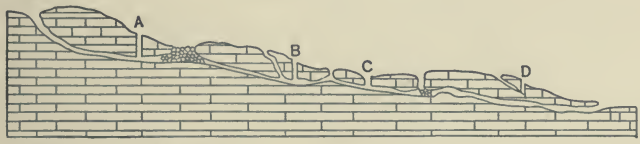
Courtesy U. S. Geol. Survey.

FIG. 5. Artesian basin. *A*, height of the water table in saturated gravel *B*. *C* is impervious strata confining the waters of *B*. *DD*, flowing wells.

catchment area being higher on both sides and gradually sloping into a valley. (Fig. 5.) A well

sunk in this valley to the water-bearing strata will produce artesian water. It must be borne in mind that water will never rise in a boring to a level with its source of supply. This is due to the fact that resistance is offered by the stratum through which the water passes. In other words, the permeability of the mass may be so slight that the water passes through with difficulty, due to the friction and a consequent loss of head.

Solution passages in limestone will often produce artesian conditions. (Fig. 6.) Such passages present



Courtesy U. S. Geol. Survey.

FIG. 6. Solution passages. *A*, *B*, *C*, *D*, wells sunk to the underground stream of water.

no obstruction to the flow of water through the rock, and being situated on an incline with sufficient head, artesian conditions are produced.

Artesian conditions are produced in many ways that are as yet little if any understood. Many theories can be advanced, but when put into practice they fall short of accomplishing the desired ends. Hydrographers tell us that many of the forces making for

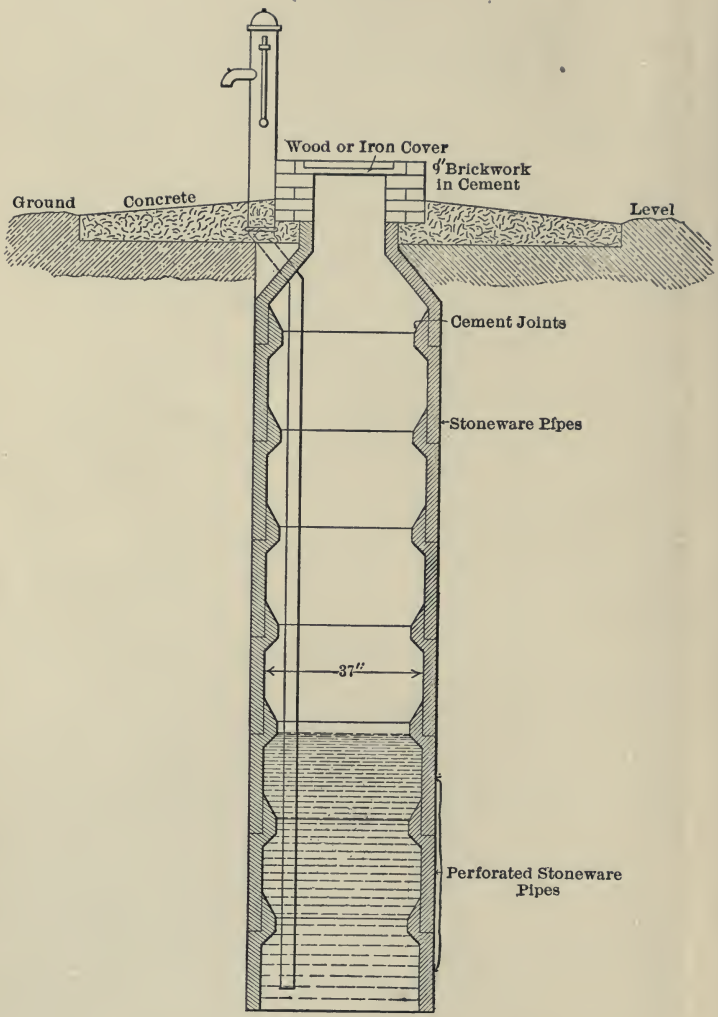


FIG. 7. Well properly protected by tile wall laid with cement joints.

artesian conditions have not as yet been explained, although they are known to exist.

Wells are subject to contamination as much as are springs, and it is as necessary to protect them properly as any natural source of supply. Except in some artesian wells, some means of raising the water to the surface must be resorted to, which greatly increases the danger of pollution. The method of closing the mouth of a well must be considered carefully, as at this point a great amount of polluting material will find entrance.

If the well is of the dug type and is walled with stone or brick, the upper six feet of the wall should be laid in cement and should extend at least a foot above the surface. Around this wall and on the surface of the ground should be placed a layer of concrete at least six inches thick and four feet wide, rising nearly to the top of the wall and sloping away in all directions. Over this should be built a double floor or platform of wood, the boards in the two floors being laid at right angles to each other, and between a layer of concrete two inches thick. This platform should extend as far as the ring of concrete beneath, and on top of it should be placed the pump. The opening in the floor through which the pump passes should be made water-tight, thus preventing surface washings gaining entrance into the well.

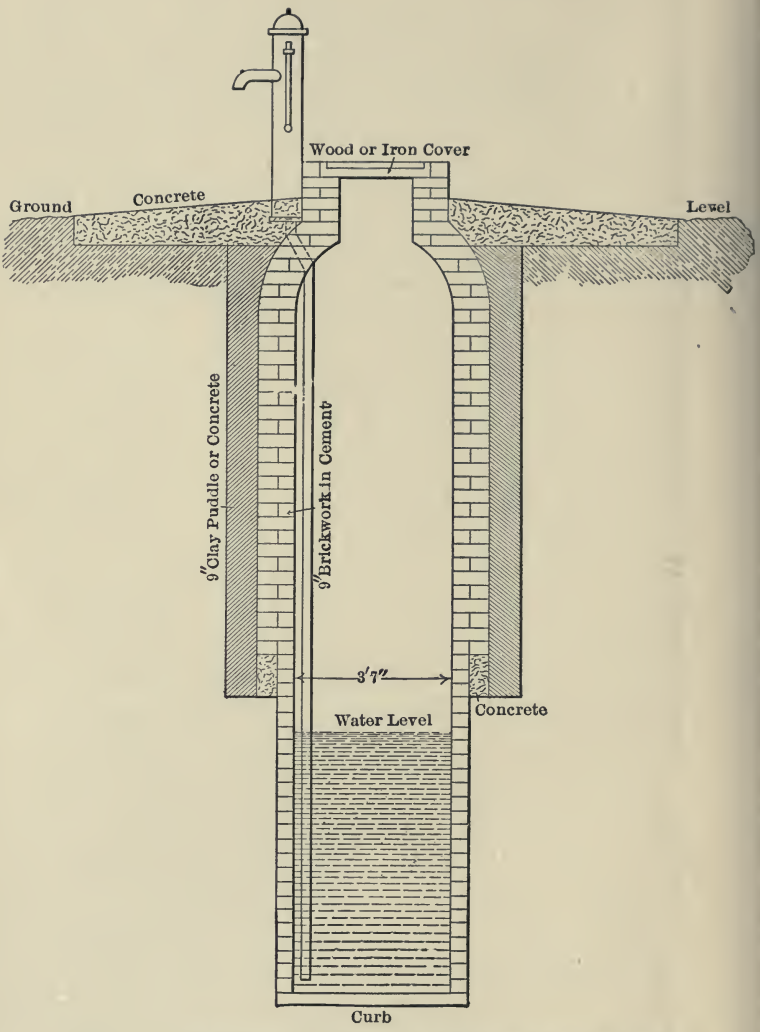


FIG. 8. Well properly protected by brick wall laid in cement.

In driven, punched, bored, or drilled wells the casing is carried down with the process of sinking the well, thus shutting out danger of contamination below the surface. The surface should be protected in a similar manner as described for dug wells, and the mouth of the well made water-tight. Figs. 7 and 8, taken from the Kansas State Board of Health Bulletin (35), will make the explanation clearer.

CHAPTER VI

WATERSHED

By watershed is meant the area immediately surrounding a water supply so situated that water falling upon it will be directed toward this supply. Drainage area and catchment are other terms sometimes used in this same connection. The watershed is of immense practical and sanitary value in relation to a given water supply. It should not be too extensive, as it would then be difficult to control properly and keep free from pollution. Neither should it be too restricted, for in rocky regions pollution might be absent from the surface, and still find its way by subterranean means to the water supply. It should be uninhabited, as any sort of habitation for either man or animals contributes to pollution by means of their bodily wastes. If inhabited, the buildings should be as far removed from the spring or well as possible and the wastes should be disposed of in such a manner as to preclude the possibility of contamination.

The watershed should be uncultivated, as cultivated soil is rich in organic matter which in the

process of decay adds substances to the water which are objectionable. A wooded area is also more valuable than an open one, as it conserves the water supply by preventing evaporation. From what has been said before, sand and gravel soil and subsoil are preferable to a rocky or clayey one.

Hand in hand with the foregoing requirements of an ideal watershed must go a knowledge of the geologic conditions underlying the area, as favorable conditions may prevail upon the surface and unfavorable conditions be found beneath.

Ability to interpret the conditions found by an inspection of a watershed, the "sanitary survey," is of immense practical value and forms one of the members of the trio of examinations which must be made in order to determine the safety and purity of a water supply; the other two being the chemical and bacteriological examinations, which will be discussed in later chapters.

Some authorities consider the sanitary survey the most important, and say that if they had to choose only one method of examining a water supply, that method would be the sanitary survey, as it would afford the most practical and satisfactory results. Fuller (10) says: "Careful examination of the spring itself and a common-sense inspection of its surroundings are usually of more value than an analysis."

The study of conditions as outlined above relating to habitations, cultivated areas, forest or plain, composition of soil and subsoil, the location upon the watershed of any possible sources of pollution, all go to make up that which we know as the sanitary survey.

Manufactories at times remotely situated from a water supply may have a decided influence in either or both of two ways: first, by discharging fumes and gases into the atmosphere, which are absorbed by the falling rain and are carried through the earth to the point of exit of the spring; secondly, by discharging waste matter upon the surface of the ground where the falling rain will carry it downward through the soil to the ground-water table; or by both methods combined.

In rocky and limestone regions this pollution by factory or other wastes may be of considerable importance, as pollution has been traced for long distances in such regions. There are several historical instances on record of the contamination of a water supply. In a certain city in the South a few years ago pollution was traced to the water supply from a source more than three-fourths of a mile distant. In this case surface pollution in the immediate vicinity of the supply was guarded against as the water was taken from deep wells situated on the side of the valley. Up

this valley less than a mile were a slaughter-house and some negro cabins in one of which there had been a case of typhoid fever prior to the outbreak in the city. The country surrounding this city is quite hilly, the prevailing formation being of limestone. The stream which ran past the slaughter-house and the negro cabins soon disappeared beneath the surface and was lost sight of. Upon investigation it was suspected that this stream might be the source from which the city wells drew their supply, and to verify it, large quantities of salt were dumped into the stream before it disappeared. Soon after, at stated intervals, samples of water were collected from the wells by vigorous pumping, and the marked rise of the chlorine content demonstrated beyond a doubt the direct connection between the wells and the underground stream.

The following incident described by Harrington (12) is of special interest in this connection.

"Epidemic at Lausen, Switzerland.

"Up to 1872, this village of 780 inhabitants had not been visited by typhoid fever, even in sporadic cases, for sixty years. On August 7th, with no previous warning, ten persons were seized, and during the next ten days nearly 60 more. The number of cases increased from day to day, until 130 persons, or one-sixth of the entire population, had been seized. So large a percentage of involvement pointed to some common cause, and the immunity enjoyed by the inmates of a

group of houses not connected with the public water supply directed attention to the latter, which was derived from a spring at the foot of a ridge about 300 feet high, between the village and the Führler valley. In this valley, at a point between one and two miles distant from Lausen, was an isolated farm where dwelt a man who, on June 10th, shortly after his return from a visit, was taken sick with typhoid fever. Before the end of July, three more cases developed in the same house. The discharges of all four were thrown into a brook in which the family washing was done, and which served to irrigate the meadows below. Whenever it was dammed up for this purpose, the volume of the water supply beyond the ridge was noticeably increased. Between July 15th and the end of the month, the meadows had been submerged by this process, and within three weeks from the beginning of the operation, the explosion occurred in Lausen.

"The sequence of events was, then, the appearance of the initial case on June 10th, and of three more in the same house before the end of July, the daily pollution of the water of the brook, the damming of the brook in the middle of July, and the appearance of the first case in Lausen on August 7th. Everything pointed to direct connection between the impounded water and the spring a mile or more distant on the other side of the ridge, and its existence was established by dumping about a ton of salt into the brook and noting the speedy appearance in the Lausen spring. As a very large amount of flour, deposited

at the same place, gave no evidence of its appearance, even in traces, it was proved that the water passed through a coarse filtering medium rather than through an open underground passage." (Pages 379–380.)

In order to detect the course of underground bodies of water, many methods have been devised and used with more or less success. These consist in introducing into a stream, spring, or well some chemical substance which can be detected later either by chemical analysis or by its color. In this way pollution is often traced which would otherwise escape detection.

The surface conditions do not always hold good for deeper formations, and indications which point, on the surface, to a safe water supply free from all possible sources of pollution may be entirely at fault when the subsurface structure and formation are examined.

Among the substances which have been used as indicators are the following: sodium, calcium, or ammonium chloride, potassium nitrate, salts of lithium and iron, all of which may be recognized by chemical or physical tests; potassium permanganate, fuchsin, Kongo red, methylene blue, and fluorescein, which dissolve in the water and are recognized by their color; starch and flour, which are suspended in water and recognized by microscopic examination; and cul-

tures of various organisms having peculiarities which permit their ready identification.

Dole (6), from whom the above classification is taken, tells us that the principal requisites in the choice of an indicator are: "(1) It should descend to and traverse the aquifer in a manner and rate similar to the water itself. (2) It should be easily and quickly detectable in the samples of water taken. (3) It should not be decomposed nor its intensity greatly affected by the materials with which it comes in contact.

"For different purposes and in different materials the selection of an indicator is varied. For determining the percentage of water entering one level from another, the chlorides are especially fitted, because the amounts present can be accurately and rapidly determined. When, however, the volumes of water are extremely large and the subterranean journey is long the amount of salt or other chloride necessary to cause an estimable change in chlorine content is so great that the experiment is often impracticable. For the study of underground flows in alluvial deposits the use of ammonium chloride and sodium chloride as electrolytes appears to be especially good. For investigating the purification power of strata through which water passes, cultures of beer-yeast have proven very satisfactory. For tracing the flow, however, of

large or small underground streams through well-defined channels of size in rocks, especially calcareous formations, fluorescein has proved superior to anything else which has been tried. Its diffusion is rapid, it is applicable under many conditions, and it can be easily detected in enormous dilutions by means of the fluoroscope when it is not present in quantities large enough to be visible to the naked eye. On account of its many admirable qualifications, fluorescein has been extensively used by the city of Paris in the study of springs from which the major part of the drinking water is taken."

Fluorescein travels at a somewhat slower rate than does the water in which it is contained. This is due in part to its greater density, which permits it to collect in low places in its path. Thus, the dye may be noted at intervals after a single application to a water supply, due to the fact that it will tend to collect in low spots and later be carried farther by an increase in the rate of flow of the water.

Fluorescein can be readily detected by the unaided eye in dilutions of .625 part per million parts of water; and by means of the fluoroscope one part in ten billion parts of water may be seen.

CHAPTER VII

MINERAL WATER

THE term mineral water as used in this work comprises all natural waters sold in bottles, or used at various resorts for drinking, bathing, or other medicinal purposes. It is hard to formulate a satisfactory definition for mineral water, as it varies so much as to composition and use that a definition as applied to waters from one locality would be totally inadequate when applied to those of another region. Definitions of various authorities have been collected and are here given.

Peale (23) defines mineral waters as "all waters put on the market, whether they are utilized as drinking or table waters, or for medicinal purposes, or used in any other way."

Ossian Henry (1) says that "mineral waters are those waters which, coming from the bosom of the earth at variable depths, bring with them substances which may have upon the animal economy a medicinal action, capable of giving rise to effects often very salutary in the different diseases affecting humanity."

M. Durian-Fardel (1) tells us that "mineral waters

are those natural waters which are used in therapeutics because of their chemical composition or their temperatures."

According to Crook (4) "the term 'mineral water' is applied to those waters which are used in the treatment of disease, either by internal administration or by external application, and which owe their virtue to their solid or gaseous constituents or to their elevated temperature."

Hessler (16) defines mineral waters as follows: "As ordinarily understood, the term 'mineral water' is applied to a water which is used in the treatment of diseases, either internally or externally, and which differs from ordinary waters in that it holds in solution certain solids or gases. Mineral water may come from springs or wells, especially deep wells."

Walton (1) says "a mineral water in the medical acceptation of the term is one, which by virtue of its ingredients, whether mineral, organic, or gaseous, or the principle of heat, is especially applicable to the treatment of disease."

Bailey (1) quotes Herpin's definition as "all waters which, by the nature of their principles or by their therapeutic action, differ from drinkable waters."

Bailey (1) himself says that "mineral waters are those natural waters which contain an excess of some ordinary ingredients, or a small quantity of some rare ingredients, and which on this account are used as remedial agents."

The First International Food Congress at its meet-

ing in 1908 determined that "a natural water is, from a commercial point of view, that which at its place of origin, as it bursts forth from the ground, is directly placed in the same receptacle in which it is delivered to the consumer." At a second session of this Congress in 1909, this definition was slightly changed and made to read as "a natural water is, from a commercial point of view, a water free from harmful germs, which at its place of origin, as it bursts from the ground, is directly placed in the same receptacle in which it is delivered to the consumer."

The Board of Food and Drug Inspection (31) of the U. S. Department of Agriculture has decided that "a natural mineral water is a water that has had nothing added to it or abstracted from it after issuing from source."

The old idea that a water to be commercially exploited must possess some magic charm for the healing of any and all the ills of life has been exploded in recent years. The water enjoying the largest sale in the United States to-day makes no other claims than freedom from impurities and adaptability for table use. Some waters widely advertised as possessing medicinal properties fall far short of measuring up to their own standard when subjected to critical and severe examination.

Waters containing only a trace of some medicinal agent, as lithium, possess no healing value over any other water for the simple reason that in order to

obtain a medicinal dose of the element it would be necessary to drink enormous quantities of the water. Hessler (16) says "it would be disagreeable to be compelled to drink a gallon of water for the sake of the few grains of lithium in it. Many of the so-called lithia waters are really very pure waters, with a trace of lithium, just enough of it so the name can be applied, although it may require the aid of a spectroscope to show that it is present."

On second thought it is seen how useless are such claims regarding this class of waters. In order to get the desired medicinal results, it is better to add the chemical in the form of a powder or tablet in definite quantity to the water, and thereby get the therapeutic effect directly.

Mineral waters are classified in various ways by various authorities, according to whether the chemical composition, medicinal property, or geological source is used as a basis.

Geologically, waters are classed as vadose and magmatic, the former being of superficial and the latter of deep-seated origin. Practically all mineral waters used commercially are of vadose origin; while many thermal springs are undoubtedly of magmatic origin. Thermal waters are sometimes spoken of as "juvenile," in that they reach the surface for the first time. Vadose waters are usually more variable in composi-

tion and flow than are magmatic waters. Waters of deep origin may contain in solution different chemical salts from those of superficial origin.

Therapeutically, waters may be classed according to the principal medicinal agent they contain, provided this agent is present in sufficient amounts to produce therapeutic action by the use of small or moderate quantities of the water.

By far the largest class of waters, therapeutically speaking, are the laxative and cathartic waters. These waters are so highly charged with the sulphates of sodium and magnesium that they exert a decidedly laxative or cathartic effect upon the system when taken in moderate amounts. Hunyadi Janos and several of the Saratoga waters are examples of this class. They act freely upon the bowels and kidneys, causing free and easy evacuations and stimulating these organs to activity when they become sluggish.

Another classification that is frequently made is that of hard and soft waters. Hard waters are those containing a large proportion of lime salts in relation to the total mineral content, while soft waters have a minimum of lime in comparison with the other mineral ingredients. Hardness is again spoken of as temporary and permanent, the former being eliminated by boiling, while the latter is not. This point

will be discussed more fully when the analysis from a chemical standpoint is considered.

Many waters possess the ability to absorb material from the walls of vessels in which they are contained. Such waters contain free carbon dioxid gas which reacts with the lead or zinc of pipes, taking these metals into solution, thereby becoming dangerous to health when taken into the system. Many cases of lead poisoning have been traced to such sources. Soft waters known to contain free carbonic acid to any extent should never be conducted through lead or zinc pipes, nor should they stand in such vessels. The carbonates of lead and zinc are formed by the action of the carbonic acid on these metals, and as these salts are readily soluble in water their presence is not suspected until symptoms of poisoning are seen.

For commercial purposes the best classification seems to be a chemical one, and that proposed by Haywood (13) is the most satisfactory yet devised. No one classification will meet the conditions found in all waters. The diverse composition of mineral waters precludes the possibility of any definite and fixed classification. General rules may be laid down, but there are so many exceptions that following them closely is out of the question. The following is Haywood's classification:

Group	Class	Subclass		
Nonthermal.	I. Alkaline	Carbonated or bicarbonated.	Sodic.	Nongaseous.
			Lithic.	
		Borated.	Potassic.	
		Silicated.	Calcic.	
	II. Alkaline saline.	Sulphated.	Magnesic.	Carbondioxated.
		Muriated.	Ferruginous.	Sulphuretted.
		Nitrated.	Aluminic.	Azotized.
Thermal.	III. Saline.	Sulphated.	Arsenic.	Carburetted.
		Muriated.	Bromic.	Oxygenated.
		Nitrated.	Iodic.	
	IV. Acid.	Sulphated.	Silicious.	
		Muriated.	Boric.	

All waters with a temperature above 70° F. are classed as thermal waters, and those with a temperature below 70° F. as nonthermal. Waters with a temperature between 70° and 98.6° F. are known as tepid or warm, while those with a temperature above 98.6° F. are classed as hot waters. All waters, no matter what their chemical composition, medicinal value, or geologic source, may fall under one or the other of these groups.

When an examination of their chemical composition is made they are grouped under the four following classes: alkaline, alkaline-saline, saline, and acid. Each class is again divided and indicated by terms which represent the predominant constituents.

According to Haywood (13) "alkaline waters are (1) those which have an alkaline reaction and contain carbonic or bicarbonic acid ions in predominating

quantities; (2) those which have an alkaline reaction and contain boric or silicic acid ions in predominating quantities, where it can be proved that the alkalinity is largely due to the presence of borates or silicates.

"Saline waters are those which have an alkaline or neutral reaction and contain sulphuric, muriatic, or nitric acid ions in predominating quantities.

"Alkaline-saline waters are between alkaline and saline. They embrace those which have an alkaline reaction and contain (1) sulphuric, muriatic, or nitric acid ions along with carbonic or bicarbonic acid ions, both classes being present as predominating constituents or those which have an alkaline reaction, and (2) contain sulphuric, muriatic, or nitric acid ions along with boric or silicic acid ions, both classes being present as predominating constituents, where it can be proved that the alkalinity is largely due to the presence of borates or silicates.

"Acid waters are those which have an acid reaction, and contain either sulphuric or muriatic acid ions in predominating quantities."

Nearly all waters contain some gas in solution, and many of them large quantities. Carbon dioxid is the gas most frequently found. Other gases, such as hydrogen sulphid, nitrogen, methane, or oxygen are frequently present. The following terms which ap-

pear in Haywood's classification are used to designate the waters containing these gases:

Nongaseous.....containing no gas.
Carbondioxated.....containing carbon dioxid gas.
Sulphuretted.....containing hydrogen sulphid gas.
Azotized.....containing nitrogen gas.
Carburetted.....containing methane gas.
Oxygenated.....containing oxygen gas.

CHAPTER VIII

CHEMICAL EXAMINATION

In a previous chapter the statement is made that three different examinations are necessary to arrive at a proper conclusion regarding the sanitary quality of a given water supply: the sanitary survey, the chemical analysis, and the bacteriological analysis. The question of the sanitary survey has already been discussed (see p. 33), and the chemical examination will now be considered. Methods of analysis will not be given in detail, but rather the interpretation of these results will be discussed. For detailed information the reader is referred to one of the many standard works upon the subject.

A matter worthy of consideration in regard to the chemical composition of a water is the variation which it will undergo during a given period. Analyses of samples of water from the same source at intervening periods will show a variation—often marked—in one or more constituents. This may be accounted for easily if we stop to consider the many underground passages which a water traverses in reaching the surface. One or more of these passages bearing water of a

certain composition may become occluded, and others may open up water-bearing strata of a different composition. In this way variations will sometimes be found in a chemical analysis of water from the same source.

The length of time elapsing between the collection and examination of samples often causes changes in the water; also the kind of vessel in which the sample is contained will influence the result. Water for chemical analysis should never be placed in any but glass vessels, these being of hard flint glass which has been thoroughly cleaned of free alkali or other soluble substances. Jugs or other earthenware vessels should never be used for the collection of samples for chemical analysis.

For sanitary purposes the determination of all the different salts in solution in the water is of no importance, as many of them bear no relation whatever to the purity of a given water. For therapeutic purposes, however, it is necessary to know the exact chemical composition of a given water in order to determine its action when taken into the human body. Infinite harm may be done a patient by the use of a water high in mineral content not adapted to his particular condition.

In the sanitary chemical analysis of a water, nine things must be looked for, as follows:

1. Free ammonia.
2. Albuminoid ammonia.
3. Nitrites.
4. Nitrates.
5. Chlorine.
6. Phosphates.
7. Organic and volatile matter.
8. Hardness.
9. Total solids.

The physical examination, which comprises the color, odor, sediment, and appearance of the sample, is usually made at the time of making the chemical analysis.

Color is determined by the use of a standard solution, known as the platinum-cobalt color standard. To this solution is given the value of 500. A given quantity of the water under examination is compared with varying dilutions of this standard and the results obtained are expressed in numerals as 10, 20, 30, etc.

Odor is determined both hot and cold; hot when the water is heated to 100° C., and is expressed in such terms as marshy, fishy, sweetish, etc. Odor is mainly due to the presence of algæ which produce a volatile oil in their growth which is given off to the water.

Sediment is the amount of insoluble matter present in the water and which collects upon the bottom of the vessel upon standing. It is also known as tur-

bidity, and is determined by comparing a given quantity of the water with a standard containing a known amount of diatomaceous earth in distilled water. Bottled samples should be thoroughly shaken just before the comparison is made.

Appearance is determined by the eye, and is expressed in such terms as clear, cloudy, etc.

Turning now to the sanitary analysis we look for the substances enumerated on page 51. The first of these is free ammonia.

Free Ammonia.—This is determined by distilling a definite quantity of water and collecting the distillate in long tubes of clear glass, known as Nessler tubes, and to each of these tubes 2 c.c. of a solution of potassium iodide, mercuric chloride, and potassium hydroxide are added. The amount of free ammonia present is determined by the color produced, and is calculated from control tubes containing a definite known amount of ammonia and the solution spoken of above, viz.: Nessler's solution.

Albuminoid Ammonia.—After the free ammonia has all been removed from the water by distillation, a solution composed of potassium hydroxide and potassium permanganate is added and the distilling process continued. Portions of this distillate are collected and tested in a manner similar to that just described for free ammonia.

The presence in a water of any considerable amounts of ammonia in either of the forms described suggests pollution. Albuminoid ammonia is really not ammonia at all, but is nitrogenous organic matter known as protein. These proteins are derived from either animal or vegetable tissue, and their presence in water shows it to have been in contact with either one or the other of these substances. As there is organic matter present in all soils it can be seen readily that all underground waters will contain at least traces of this nitrogenous matter.

A water, the source of which is protected absolutely from animal pollution, but which may be surrounded by a thick vegetable growth, such as forest, will show the presence of albuminoid and free ammonia often in considerable quantities, and yet be perfectly pure and safe to use; another argument for a complete knowledge of the source of a water before final judgment is passed thereon.

When a water is polluted by animal wastes and the ammonias are present in any considerable quantities, bacteriological examination will usually reveal the presence of organisms of a type found in contaminating material. While if a water whose ammonias are due to vegetable matter is examined bacteriologically the characteristic microörganisms will be absent.

There is what is known as a nitrogen cycle, of which

albuminoid ammonia is the first step, and free ammonia the next. After free ammonia comes nitrites which are finally changed to nitrates, thus completing the cycle. We will now pass to the discussion of nitrites and nitrates and then complete the discussion of all four forms of nitrogen.

Nitrites.—Nitrites are tested for by placing a definite quantity of the water under examination in Nessler tubes and after adding a drop or two of strong hydrochloric acid to each tube a small quantity of a solution of sulphanilic acid and naphthalamine hydrochloride are added. Control tubes containing a known amount of nitrite are treated in the same way and the red color produced by the reaction of the various solutions in the known and unknown tubes is compared. From the results obtained the amount of nitrite present is determined.

Nitrates.—Nitrates are determined by evaporating a given quantity of water to dryness and moistening the residue with phenolsulphonic acid. After the residue is moistened, distilled water and strong ammonia are added. The whole is then transferred to Nessler tubes and the color produced is compared with tubes containing known amounts of a nitrate, the amount of nitrates present in the sample being calculated from these data.

Referring now to the nitrogen cycle we find that

the form in which nitrogen is introduced into the water is protein or albuminoid ammonia. This is transformed into free ammonia by means of certain species of bacteria which were present in the soil through which the water passed. It might be well to state here that free ammonia may find its way into the soil and directly into water supplies by means of fumes which are present in the air in the vicinity of industrial plants such as chemical factories. Its presence under such conditions would have no sanitary significance unless present in sufficient quantities to have a direct action upon the living organism.

By the action of the bacteria which have just been mentioned the free ammonia is changed into nitrites, and these in turn are converted into nitrates. When this form of nitrogen is reached no further change can take place, and we have a stable compound which cannot be further broken up or changed. The two forms of ammonia and nitrites are transition forms in this process and show more or less recent pollution. When the ammonias are high and the nitrates low, with a trace of nitrites, it indicates quite recent additions of nitrogenous matter to the water. When nitrites are more in evidence and the ammonias are low, it suggests that pollution has been quite recent but is lessened. When both ammonias and nitrites are low and nitrates high, it shows that polluting

material has gained access to the water some time in the past, but that no pollution is taking place at the present time. Such a water at the time the examination was made might be safe to use, but the fact that it showed past pollution would suggest the necessity of safeguarding it against subsequent pollution.

This process of change from ammonias to nitrites and then to nitrates is known as oxidation. The opposite process, known as reduction, may take place under certain conditions, and the nitrates present in a water may be changed back to nitrites and these in turn converted into free ammonia, but never into albuminoid ammonia. When some chemicals, such as iron in one form, are present in the strata through which the water passes, they will act upon any nitrates which may be present and reduce them to nitrites. Such conditions bear no sanitary significance whatever. Usually when nitrites are present due to the reduction of nitrates the ammonias will be very low, or entirely absent. So we find that the question of interpreting analytical results must be looked at from all points of view before a final decision is reached.

Chlorine.—The test for chlorine is quite simple and is easily made. To a definite quantity of water in a Nessler tube add a small amount of a solution of potassium chromate which produces a yellow color.

A standard solution of silver nitrate is now added until the yellow color disappears and a reddish tinge is given to the water. From the amount of silver nitrate solution used the amount of chlorine present is calculated.

In interpreting the results of a chlorine analysis it is very important to have some knowledge regarding the geological formations in the vicinity of the source, with special relation to salt deposits. If near the ocean, or near salt deposits such as are found in the vicinity of Syracuse, N. Y., pure waters are likely to contain relatively large quantities of chlorine. It is good practice to obtain analyses of other waters in that same vicinity in order to get the average chlorine content of the region. On the other hand if there are no known salt deposits in the vicinity, and if there is a possibility of surface washings entering the well or spring, contamination is probable when high chlorine is found. Urine of man and other animals contains a large amount of chlorine, and if sewage has access to a water supply it can be determined readily by the amount of chlorine present upon examination. Taken in connection with high ammonias and nitrites it is a pretty certain index of pollution.

Phosphates.—To test for phosphates take a definite amount of the water and add a little nitric acid. Evaporate to dryness and heat for two hours in an

oven. Moisten with cold water and transfer to a Nessler tube. Add some ammonium molybdate solution and nitric acid and after standing a few minutes compare with a standard solution of phosphate treated with the ammonium molybdate and nitric acid solutions.

Like chlorine, phosphates indicate pollution when found in waters, as excretions of all animals contain large amounts of phosphates. In certain localities known to contain beds of phosphate, they may be present and bear no sanitary significance, but it is safe to say that a water containing appreciable amounts of phosphates should be looked upon with suspicion.

Organic Matter.—The presence of organic matter in water may be tested for and reported in either of two ways: (1) by a chemical test using potassium permanganate and oxalic acid, when the results are reported as oxygen required, or (2) by heating the weighed residue obtained by evaporating a definite quantity of the water to dryness, raising the temperture to a dull red heat, and after cooling again weighing, loss of weight being the amount of organic and volatile matter present in the water.

The significance of the presence of organic matter in any quantity in a potable water, is not so much the actual amount present, for this is usually quite small

in a pure water, but organic matter is necessary as food for bacteria, and the more there is present in any water the more food, and consequently the greater the number of organisms that will be found upon examination. A water may be rich in organic matter and contain no bacteria, but if by any means bacteria gain access to it they will multiply very rapidly owing to the large amount of food material, provided other conditions for their development are favorable.

Many surface waters contain large amounts of organic matter, such as the Dismal Swamp in Virginia, but the absence of any polluting sources makes them safe to use. Such waters are usually dark in color, and not at all inviting to the senses.

Hardness.—Hardness is the name given to a condition produced by the amount of sulphates, chlorides, and carbonates of calcium, or lime, and magnesium which are present in a water. Hardness is spoken of as temporary and permanent. The temporary hardness is that which can be eliminated by boiling, and is due to the presence of the carbonates and bicarbonates of the elements mentioned above. When water containing carbonates and bicarbonates of these elements is boiled the carbon dioxide gas which holds these salts in solution is driven off and the insoluble carbonates are deposited upon the sides and bottom

of the vessel. This is the source of the scale so often seen in vessels used repeatedly for boiling water.

The sulphates and chlorides of calcium and magnesium cannot be precipitated by boiling, and they constitute the permanent hardness. These chemical salts are spoken of as incrustants when used in connection with boiler-feed waters, and when present in even moderate amounts cause bad effects upon the boilers.

An objection is frequently raised against the use of hard waters for drinking purposes, and the argument is advanced that too much lime will be taken into the system by the continued use of such waters. Collectively speaking the amount of lime present in a gallon of very hard water will not amount to more than a few grains, and as only a glassful or two of water is consumed at one time, and not more than half a gallon is used in a day, the argument against such a water falls flat. It would be necessary to drink gallons of such water at a time in order to get enough lime to have any effect upon the system.

The taste is imparted to most waters by the mineral matter which is held in solution, hence the flat, insipid taste of distilled water. After a person becomes accustomed to the taste of a particular water another water does not appeal to him and does not satisfy his thirst to so great an extent. After having been

accustomed to a moderately hard water a soft water is very flat and tastes more like distilled or rain water.

Total Solids.—The determination of total solids is made by evaporating a definite quantity of water to dryness in a weighed platinum dish and again weighing. The increase in weight is the amount of chemical salts that was in solution in the water and which was precipitated by evaporation.

For sanitary purposes the mere determination of total solids is sufficient, but for a complete chemical analysis this residue must be examined further to determine its composition. The medicinal properties of waters depend upon the various chemicals in solution, and these must be known in order to make intelligent use of their therapeutic agents. Some waters being highly mineralized have a well-known and decided therapeutic action when taken into the system. In potable waters for domestic use the amount of mineral matter present is so small that no therapeutic action is exerted unless fortified by the addition of chemicals. When waters are sophisticated by such means they cease to be natural waters and must be classed with the artificial. The presence of mineral matters in small amount in solution renders them capable of being absorbed by the system and used in the building and repair of the body tissues.

The same salts are taken in much larger quantities in our solid food, and most of the mineral matter used in the upkeep of our bodies is obtained in this manner. So the principal function of a pure potable water is to quench thirst and help in keeping the excretory organs, as the skin, kidneys, and bowels, in good working condition.

CHAPTER IX

BACTERIOLOGICAL EXAMINATION

THE bacteriological examination of a water is conceded by many to be the most important of any of the methods now in use. Especially is this so when considering underground waters for commercial purposes. It is taken for granted that no business organization would embark in the water trade until they had a source of supply above criticism. Then, the surroundings being constant, the chemical analysis from the same source would not vary beyond the allowable limits and only the bacteriological examination would show daily changes.

Each step in the manipulation of the water after leaving the source until it is placed in the container in which it reaches the consumer must be carefully guarded to prevent the entrance of undesirable bacteria.

The bacteriological examination of a water is usually undertaken for two reasons, (1) to ascertain the average number of bacteria in a given quantity of water, usually one cubic centimetre, or about one-fourth teaspoonful; (2) to determine the presence or

absence of contaminating bacteria. The complete examination, that is, the isolation and identification of each organism found, is seldom made unless the examiner is interested in the purely scientific side of the question.

It is also impossible to determine all the bacteria present in a water. Some will not grow upon the media used, others will not grow in the presence of air, and still others require different conditions of light and temperature from those used in routine bacteriological work. Thus the number of bacteria as reported in a sample of water is only a fraction of the number really present. However, as all samples are, or should be, reported upon similar methods of examination, the results are comparable even though the total number present in all samples is not determined.

Briefly, the method of examination of a given sample of water is as follows: The sample is collected in a clean, sterile bottle with a tight-fitting glass stopper, and of about four ounces capacity, and transferred to the laboratory with as little delay as possible. If the time elapsing between collection and examination exceeds an hour the sample should be packed in ice. Sterile glass plates known as Petri plates with loosely fitting glass covers, also sterile, are labeled to correspond to the number of the sample. After thor-

oughly shaking the bottle to secure an intimate mixture of the contents, one cubic centimetre is withdrawn by means of a sterile pipette and placed in a Petri dish. To another dish one-tenth of a cubic centimetre is added, to another one-hundredth of a cubic centimetre, etc., depending upon how high a dilution is required. Sterile distilled water is used for diluting purposes. Into these plates is then poured some warm, sterile, melted gelatine which is thoroughly mixed with the water and set aside to cool. After the gelatine film upon the bottom of the plate has become cold and solidified, the plates are placed in a moist dark chamber, the temperature of which is maintained at or near 20° C. They remain here for 48 hours. At the end of this time any bacteria which may have been present in the water will have grown and multiplied until the masses of bacteria can be seen with the aid of a low-power lens, and often with the unaided eye. The number of masses, or colonies of bacteria, as they are called, are then counted, the number found on the diluted plates being multiplied by ten or one hundred or more as the case may be, and the average taken. This average is given as the number of bacteria in a cubic centimetre of the water. For instance, if the sample of water showed on the plate containing one cubic centimetre of the water 700 colonies, on the plate

containing one-tenth cubic centimetre 80 colonies, and on the plate containing one-hundredth cubic centimetre 9 colonies, the average of these three plates after the proper multiplications had been made would be 800. We would, therefore, say that this particular sample of water contained 800 bacteria per cubic centimetre.

At the time of preparing the Petri plates with gelatine, varying quantities of the water, usually ten, one, and one-tenth cubic centimetres, are added to sterile solutions containing some form of sugar, dextrose or lactose, in specially constructed tubes. This is for the purpose of determining the presence or absence of bacteria which produce gas in sugar solutions. If this type of bacteria is present in the water it will break down the sugar into carbon dioxide, a gas, and alcohol. The gas will collect in the closed arm of the tube, and its nature can be determined by analysis. Various liquids containing the sugar in solution may be used for this purpose, such as peptone water, beef broth, ox bile, liver broth, etc., depending upon the character of the water to be examined. For commercial waters the ox bile and beef broth to which some lactose has been added are about the best. Both solutions are rendered sterile by heating. After being inoculated with the water under examination these tubes are placed in an incubator at a

temperature of 37° C. to 38° C. for 48 hours. If no gas production has taken place at the end of this time the test is considered negative. If, however, there is gas production the examination is carried further in order to isolate and identify the organism causing the gas formation.

To do this, some of the sediment in the tube showing gas is inoculated into sterile tubes of agar-agar to which lactose and a small amount of sterile litmus solution have been added. This litmus turns blue in an alkaline medium and red in an acid medium. The agar-agar should be slightly alkaline when inoculated. After incubating at 37° C. for 24 hours, numerous colonies of bacteria will be found growing on the plate, and among them will be found some which are surrounded by a red area in the blue field; other colonies will have no effect upon the medium. The red colonies are usually the cause of the gas production in the original tube. Some of these red colonies are transferred to tubes of the sugar solution originally used and again tested for gas production, and if gas is produced it is proof that the organism causing the original gas production has been isolated.

At the same time that gelatine plates are made and tubes inoculated for gas production some of the water is placed in plates and agar-agar added in place of gelatine. As soon as cool these plates are placed in

the incubator at 37° to 38° C. for 24 hours, and at the end of this time they are examined for the presence of colonies. Bacteria which develop at this temperature, which is about the temperature of the human body, are looked upon with suspicion. Unpolluted water will show very few bacteria capable of development at this temperature, the species which grow at 20° C. being able to grow feebly or not at all at the higher temperature. Bacteria which grow best at the higher temperature rapidly die out when added to pure water, unless its temperature is raised and there is organic matter present to serve them as food. So if a given water upon examination shows many bacteria capable of developing at 37° C. it should be regarded with suspicion, especially if among these bacteria are found some that produce gas.

It does not seem necessary in a work of this sort to enter into a description of the preparation and use of the various culture media employed in the examination of water, and the reader is referred to any standard text-book upon the subject where this information may be found in detail. A discussion of the results obtained is proper and necessary to the understanding of an analysis, especially from a sanitary point of view.

The bacteriological examination of water is a

delicate operation in that so many factors must be considered, many of which are negligible in a chemical analysis but are of the utmost importance from the bacteriological point of view. Bacteria multiply very rapidly, only a half hour being necessary for the division of a single organism into two. As a consequence, the total number of bacteria present in a given sample of water will have very little significance from a sanitary standpoint unless the time elapsing between collection and examination is known. All natural waters contain food for bacteria in the form of larger or smaller amounts of organic matter and if there is much delay in the examination of a water after collection the bacteria will markedly increase. A water showing only a few bacteria at the time of collection will show thousands or perhaps millions if examined at the end of two or three days. The following table taken from Mason (21) will serve to illustrate this point:

Immediate	15.9° C.	48	bacteria per c.c.
After 2 hours	20.6° C.	125	" " "
After 1 day	21.0° C.	38,000	" " "
After 2 days	20.5° C.	125,000	" " "
After 3 days	22.3° C.	590,000	" " "

The above statements should be modified by saying that the temperature at which the sample was held,

also the absence or presence of light, has a marked influence. Water kept in the dark at a warm temperature will show a marked increase in its bacterial content as against one kept at a low temperature and in the light. Light is rapidly fatal to bacteria, and sunlight is one of our best disinfectants. Bacteria multiply rapidly up to a temperature of 37° C., and some even higher, but temperatures over 45° C. inhibit their development and if long-continued are fatal. Likewise the nearer the temperature approaches freezing, the less growth there is, but a low temperature can be withstood for a longer period than can a high one. Bacteria will live in ice for several weeks, but at the end of six months ice is sterile, even when cut from contaminated fields. So we see that the factors of light and temperature exert a marked effect upon the bacterial content of waters.

Another condition easy of demonstration in the laboratory is that waters kept in small quantities show an increase of bacteria over those kept in larger quantities. Water placed in a two-ounce bottle and in a five-gallon bottle and kept under similar conditions will show a greater increase of bacteria in the smaller container. This furnishes one argument against keeping water bottled for a great length of time before being used. There is a limit to this

multiplication, however, for as soon as the food material is exhausted the bacteria will die, and after this time the bottle of water will be sterile.

It is thus seen that the total number of bacteria in themselves in a sample of water has no real sanitary value. The real significance lies in the kinds of bacteria present.

In order to determine the different varieties of bacteria present in a water a more complicated procedure is necessary. Many workers along this line have evolved methods for the separation and identification of various organisms. From a sanitary point of view those bacteria which are capable of producing diseased conditions when taken into the system are of the most importance; and it is toward the isolation of such germs as cause typhoid fever, cholera, and dysentery, and other water-borne diseases, that the greatest effort has been directed.

Up to within the last few years the germ causing typhoid fever had been isolated from polluted water a very few times, not more than six or eight. Since that time methods and culture media have been perfected whereby it has been more freely identified. The organism which is most frequently found and which is taken as an index of pollution is the so-called colon bacillus, or rather colon group of bacteria. Jackson (17) has shown that there are several mem-

bers of this group which have a common origin in that they are found in the intestinal contents of warm-blooded animals. The germ causing typhoid fever is also found in the intestinal discharges of persons suffering from the disease. Having a common habitat, both germs are frequently present in contaminating material when of human origin.

As previously stated, the colon group of bacteria is easily identified in water examinations, and when present suggests the possibility of the presence of typhoid, cholera, or dysentery germs, as all three are found in the intestinal discharges of persons suffering with these diseases. Unfortunately, no method has yet been devised whereby the colon bacillus of human origin can be differentiated from that of other animals. If such was the case it would be an easy matter to know whether the pollution of a given water supply was of a dangerous or harmless nature. For while the presence of colon bacilli from whatever source is objectionable from an æsthetic point of view, their significance as indicating disease would be greatly diminished if it could be shown that their original source was from birds or other animals not subject to diseases transmissible to man.

Colon bacilli are found almost everywhere: in the soil, in the air, especially in the dust of roadways and streets; they are especially abundant in sewage, in

cultivated fields—in fact, wherever warm-blooded animals are found there is the colon bacillus in greater or less numbers. It is capable of multiplication outside of the intestine, therefore its presence in a water in small numbers may have no great sanitary significance; for it may have been isolated from its normal environment for a long time before reaching a water supply, in the meantime undergoing marked changes as far as bacterial associates are concerned. It may have lost all connection with the material in which it left the body, and the rapid multiplication which any germ undergoes under similar conditions may have so altered its character and associates as to make it a perfectly harmless type when found in a water. As it is a much hardier germ than the typhoid bacillus, it will easily outlive its pathogenic associate and more readily adapt itself to new surroundings. However, it is a safe rule to look upon all waters with suspicion which show the presence of the colon bacillus in amounts of ten cubic centimetres or less in the majority of examinations. Some authorities maintain that it should never be found in any amount of water that is pure, while others are more liberal in their view and do not condemn a water showing this germ occasionally present in ten cubic-centimetre amounts or more. More leniency is shown in dealing with public water

supplies than with commercial mineral waters, and rightly so; for in most instances a public supply must be taken from a river or lake whose watershed is subject to contamination which is beyond the control of the community supplied, while commercial waters are, or should be, so safeguarded as to preclude the possibility of pollution reaching even the vicinity of the source from which the supply is drawn. Therefore, the colon bacillus should never be found in such waters at their source. If found in the bottled product it is evidence that contamination has crept in at some point in the handling. Examination of a sample from the source will show whether it is polluted or not; and if found pure, the course of the water must be traced through the various steps in the handling.

As a good potable water offers rather an uncongenial environment for the colon bacillus, it will not live very long amid such surroundings. The writer has found in his own laboratory that in bottled waters it is impossible to recover this organism after 35 days, even when added as a vigorous culture and in comparatively large quantities to the bottled product. Here again the elements of temperature and light enter largely into the calculations. The time here given was for water kept in five-pint bottles in diffuse light and at room temperature

18° to 22° C. Water kept cold and in the dark will show colon bacilli for a greater length of time.

It is readily seen that water in its passage through the soil collects large numbers of bacteria of all kinds, and while it loses many of them in its further course, some of them find their way to the surface with the water as it emerges as a spring. These bacteria are accustomed to living amid cool surroundings, and therefore readily adapt themselves to an aquatic life. Such organisms are what some writers term "normal water bacteria," but as the kinds of bacteria in different waters will vary as the composition of the soil and subsoil varies, it is seen that each water supply, to a large extent, must have its own peculiar bacterial flora. When the surroundings are protected from pollution the dangers from pathogenic germs are eliminated and the "normal bacteria" for that particular location will be of a harmless type.

The bacteria found in a water and which have been derived from an uncontaminated soil will grow best at the temperature of that water. Polluting bacteria, especially those of a disease-producing type, and the colon bacillus grow best at the body temperature, 38° C., and will grow feebly or not at all at the normal temperature of the water in which they were found. If, upon examination of a water, a number of colonies of bacteria are found growing at a temperature of

20° to 22° C. and few or none growing at a temperature of 38° C., it is to be presumed that the source is free from pollution. If more bacteria are found growing at 38° than at 20° C. it is evidence that contaminating organisms are finding their way into the water supply, and that being the case, there is danger of disease-producing bacteria being present. Therefore, the relative number of bacteria growing at body and room temperature is a fair index of the sanitary condition of a water supply.

Other bacteria aside from the colon group are capable of producing gas in the various sugar media, and it is not enough to base an opinion upon the quality of a water alone from the point of gas production. When gas is formed in lactose bile solution it has been determined that the colon bacillus is the cause in over 95 per cent of the cases. When plain lactose broth is used the number of times this organism is found as the cause of gas production varies from 50 per cent to 80 per cent. Solutions containing dextrose show gas production by many other organisms than the colon bacillus and is not so reliable an index of pollution as are lactose solutions. Dextrose liver broth will give all gas producers present, both attenuated and vigorous, and the examination must be carried to the point of verification when this medium is used.

For purposes of identification of the colon group of bacteria it is necessary to plant it in various culture media and study its reaction. To be classed as belonging to the colon group of organisms, a germ should give the following reactions:

A uniform turbidity in beef broth.

A moderate, white, moist growth on agar slants.

Should not liquefy gelatine.

Should coagulate and acidify milk.

Should produce gas in dextrose and lactose solutions, also in lactose bile; gas production in saccharose variable.

Should produce indol and nitrites.

Should decolorize when treated with Gram stain, and upon measurement, should be from two to four microns long, and .4 to .7 micron broad.

CHAPTER X

MICROSCOPICAL EXAMINATION

The microscopical examination of a water is in itself a large subject and can only be touched upon in a work of this character. Literally speaking, the microscopical examination should include everything not visible to the unaided eye; but as the science of water analysis has advanced, the bacteriological examination has come to occupy a place of first importance in a field distinctively its own, and the microscopical examination deals with minute plants and animals found in some waters. The bacteriological examination has to do with the safety of a water from a disease-producing standpoint; the microscopical examination deals more directly with the æsthetic qualities, such as taste, odor, turbidity, etc.

Whipple (34) says: "By far the most important service that the microscopical examination renders is that of explaining the cause of taste and odor of a water and of its color, turbidity, and sediment. Several of the microscopical organisms give rise to objectionable odors in water, and, when sufficiently

abundant, have a marked influence upon its color. They also make the water turbid and cause unsightly scums and sediments to form. Upon all such matters related to the æsthetic qualities of a water the microscopical examination is almost the only means of obtaining reliable information."

Plankton is the general name given to the microscopical aggregation which is investigated in any given sample of water. The term as used embraces plants and animals that float about in the free state, also larvæ, egg masses, etc., of higher animals. It includes diatoms, algæ, fungi, protozoa, etc.

According to Whipple (34) "ground water collected directly from the soil before it has had an opportunity to stand in pipes or be exposed to the light is almost invariably free from microscopic organisms. . . . It is only as a ground water becomes a surface water that the microscopic organisms develop."

Examinations made by the Massachusetts State Board of Health, and quoted by Whipple (34) show that these minute organisms are rarely found in spring waters. Certain types are found in some wells, especially in the tubes of driven wells, and in water containing quantities of iron and organic matter, but with a less amount of oxygen than normal.

Surface water is usually rich in microscopic life which at times becomes very troublesome in reservoirs, causing disagreeable odors and tastes. The slimy growth and scum so often seen on the surface of comparatively still bodies of water are due to the presence and growth of various microscopic forms. They are found at times on the interior of service pipes and may become so numerous as to interfere seriously with the water supply by occluding the passage-way in the pipes.

The persistence of microscopic organisms in a given water supply is dependent upon three things: temperature, light, and food material. As a general rule, a warm temperature, 70° to 90° F., plenty of light, and a water rich in nitrogenous organic matter are most favorable conditions for the development of microscopic organisms. The light factor here is just opposite to that most favorable for bacterial development, as we have seen that light is inhibitory in its action on bacteria. The factors making for the development of microscopic organisms is evidenced by the abundant scum formation seen on the surface of stagnant ponds and other bodies of water during the warm summer weather. There are exceptions to this, however, and some forms of microscopic plant life grow only in cold waters in dark places, such as service pipes, covered reservoirs, etc. Some

forms require the presence of minerals, such as iron or manganese, in order to thrive.

In order to purify a water of these objectionable elements, it is necessary either to filter it or add a disinfectant, as copper sulphate. From one to two parts of copper sulphate in one million parts of water is sufficient to destroy most forms of algæ, and such minute quantities have no effect when taken into the system. A higher concentration (1 : 400,000) is rapidly fatal to bacteria in water, as a solution of this strength will kill typhoid germs in 24 hours Jordan (18).

APPENDIX

USEFUL RULES AND TABLES

USEFUL RULES

To find the capacity in gallons of a cylinder of given dimensions, square the diameter, multiply by the length, and by 0.0034 when dimensions are in inches; and by 5.875 when the dimensions are in feet.

To find the weight of water in a given cylinder, multiply the capacity in cubic feet by 62.25, or gallons by 8.33.

To find the number of barrels of 31.5 gallons, or number of gallons in tanks or cisterns, multiply the square of the diameter by depth in feet; for barrels, multiply by 373 and divide by 2,000; for gallons, multiply by 47 and divide by 8.

To find capacity in gallons of rectangular tanks, determine the number of cubic feet and divide by 7.4805.

Under a pressure of 15 pounds per square inch water can be compressed 0.00004663 of its volume.

A column of water one foot high exerts a pressure of .433 pounds per square inch, or 62.352 pounds per square foot.

A flow of one cubic foot per second equals 448.31 gallons per minute; 646,317 gallons per 24 hours; or 3741.3 pounds of water per minute.

Doubling the diameter of a pipe increases its capacity four times.

To measure the flow of an open stream, measure the depth of the water at from 6 to 12 points across the stream at equal distances between. Add all the depths in feet together and divide by the number of measurements: this will be the average depth of the stream, which, multiplied by its width, will give its area or cross-section. Multiply this by the velocity of the stream in feet per minute, and the result will be the discharge in cubic feet per minute of the stream.

The velocity of the stream can be found by laying off 100 feet of the bank and throwing a float into the middle, noting the time taken in passing over the 100 feet. Do this a number of times and take the average; then, dividing this distance by the time gives the velocity at the surface. As the top of the stream flows faster than the bottom or sides—the average velocity being about 83 per cent of the surface velocity at the middle—it is convenient to measure a distance of 120 feet for the float and reckon it as 100 (Kent).

WEIGHTS AND MEASURES

One gallon of water weighs 8.331 pounds.
One cubic foot of water weighs 62.32 pounds at 39° F.
267.38 gallons of water weigh a ton.
35.746 cubic feet of water weigh a ton.
One gallon of water measures 231 cubic inches.
One cubic foot of water is equal to 7.4805 gallons.
One cubic centimetre (c.c.) = .033 oz.
One ounce (oz.) = 29.574 c.c.
One c.c. = 16 drops (approximately).
One litre (L) = 1.056 qts.

One quart = .946 L.

One gallon = 3.785 L.

One grain per gallon = 1.71 parts per hundred thousand.

One grain per gallon = 17.1 parts per million.

One part per hundred thousand = .585 grain per gallon.

One part per hundred thousand = .1 part per million.

One part per million = .0585 grain per gallon.

One part per million = 10 parts per hundred thousand.

CYLINDRICAL VESSELS; TANKS, CISTERNS, ETC.

Diameter in Feet and Inches, Area in Square Feet, and U. S. Gallons Capacity for One Foot in Depth.

$$1 \text{ gallon} = 231 \text{ cubic inches} = \frac{1 \text{ cubic foot}}{7.4805} = 0.13368 \text{ cubic feet.}$$

Diam.		Area	Gals.	Diam.		Area	Gals.
Ft.	In.	Sq. ft.	1 foot depth	Ft.	In.	Sq. ft.	1 foot depth
1		.785	5.87	3	10	11.541	86.33
1	1	.922	6.89	3	11	12.048	90.13
1	2	1.069	8.00	4		12.566	94
1	3	1.227	9.18	4	1	13.095	97.96
1	4	1.396	10.44	4	2	13.635	102.00
1	5	1.576	11.79	4	3	14.186	106.12
1	6	1.767	13.22	4	4	14.748	110.32
1	7	1.969	14.73	4	5	15.321	114.61
1	8	2.182	16.32	4	6	15.90	118.97
1	9	2.405	17.99	4	7	16.50	123.42
1	10	2.640	19.75	4	8	17.10	127.95
1	11	2.885	21.58	4	9	17.72	132.56
2		3.142	23.50	4	10	18.35	137.25
2	1	3.409	25.50	4	11	18.99	142.02
2	2	3.687	27.58	5		19.63	146.88
2	3	3.976	29.74	5	1	20.29	151.82
2	4	4.276	31.99	5	2	20.97	156.83
2	5	4.587	34.31	5	3	21.65	161.93
2	6	4.909	36.72	5	4	22.34	167.12
2	7	5.241	39.21	5	5	23.04	172.38
2	8	5.585	41.78	5	6	23.76	177.72
2	9	5.940	44.43	5	7	24.48	183.15
2	10	6.305	47.16	5	8	25.22	188.66
2	11	6.681	49.98	5	9	25.97	194.25
3		7.069	52.88	5	10	26.73	199.92
3	1	7.467	55.86	5	11	27.49	205.67
3	2	7.876	58.92	6		28.27	211.51
3	3	8.296	62.06	6	3	30.68	229.50
3	4	8.727	65.28	6	6	33.18	248.23
3	5	9.168	68.58	6	9	35.78	267.69
3	6	9.621	71.97	7		38.48	287.88
3	7	10.085	75.44	7	3	41.28	308.81
3	8	10.559	78.99	7	6	44.18	330.48
3	9	11.045	82.62	7	9	47.17	352.88

CYLINDRICAL VESSELS, ETC. (Cont.)

Diam.		Area	Gals.	Diam.		Area	Gals.
Ft.	In.	Sq. ft.	1 foot depth	Ft.	In.	Sq. ft.	1 foot depth
8		50.27	376.01	18		254.47	1903.6
8	3	53.46	399.88	18	6	268.80	2010.8
8	6	56.75	424.48	19		283.53	2120.9
8	9	60.13	449.82	19	6	298.65	2234.0
9		63.62	475.89	20		314.16	2350.1
9	3	67.20	502.70	20	6	330.06	2469.1
9	6	70.88	530.24	21		346.36	2591.0
9	9	74.66	558.51	21	6	363.05	2715.8
10		78.54	587.52	22		380.13	2843.6
10	3	82.52	617.26	22	6	397.61	2974.3
10	6	86.59	647.74	23		415.48	3108.0
10	9	90.76	678.95	23	6	433.74	3244.6
11		95.03	710.90	24		452.39	3384.1
11	3	99.40	743.58	24	6	471.44	3526.6
11	6	103.87	776.99	25		490.87	3672.0
11	9	108.43	811.14	25	6	510.71	3820.3
12		113.10	846.03	26		530.93	3971.6
12	3	117.86	881.65	26	6	551.55	4125.9
12	6	122.72	918.00	27		572.56	4283.0
12	9	127.68	955.09	27	6	593.96	4443.1
13		132.73	992.91	28		615.75	4606.2
13	6	143.14	1070.8	28	6	637.94	4772.1
14		153.94	1151.5	29		660.52	4941.0
14	6	165.13	1235.3	29	6	683.49	5112.9
15		176.71	1321.9	30		706.86	5287.7
15	6	188.69	1411.5	30	6	730.62	5465.4
16		201.06	1504.1	31		754.77	5646.1
16	6	213.82	1599.5	31	6	779.31	5829.7
17		226.98	1697.9	32		804.25	6016.2
17	6	240.53	1799.3	32	6	829.58	6205.7

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CAPACITY OF PIPES OF VARIOUS SIZES IN CUBIC FEET AND GALLONS.

Diam. inches	Cu. ft.	Gals.	No. feet for 1 gal.	Diam. inches	Cu. ft.	Gals.	No. ft. for 1 gal.
¼	.0003	.0025	392	9	.4418	3.305	.30
½	.0014	.0102	98	9½	.4922	3.682	.271
¾	.0031	.0230	43.66	10	.5454	4.08	.24
1	.0055	.0408	24.4	10½	.6013	4.498	.22
1¼	.0085	.0638	15.67	11	.6600	4.937	.202
1½	.0123	.0918	10.80	12	.7854	5.875	.17
1¾	.0167	.1249	8	13	.9218	6.895	.144
2	.0218	.1632	6.10	14	1.069	7.997	.125
2¼	.0276	.2066	4.83	15	1.227	9.180	.108
2½	.0341	.2550	3.92	16	1.396	10.44	.095
2¾	.0412	.3085	3.24	17	1.576	11.79	.084
3	.0491	.3672	2.72	18	1.768	13.22	.075
3½	.0668	.4998	2	20	2.182	16.32	.061
4	.0873	.6528	1.50	22	2.640	19.75	.05
4½	.1104	.8263	1.21	24	3.142	23.50	.042
5	.1364	1.02	.98	26	3.687	27.58	.036
5½	.1650	1.234	.81	28	4.276	31.99	.031
6	.1963	1.469	.68	30	4.909	36.72	.027
6½	.2304	1.724	.58	36	7.069	52.88	.018
7	.2673	1.999	.50	42	9.621	71.97	.013
7½	.3068	2.295	.43	48	12.566	94.00	.0106
8	.3491	2.611	.38	....	.....	.....	.....
8½	.3941	2.948	.339	....	.....	.....	.....

COMPARATIVE TABLE OF TEMPERATURES, FAHRENHEIT TO CENTIGRADE.

F	C	F	C	F	C	F	C	F	C	F	C	F	C
−40	−40	−3	−19.4	33	+0.6	69	20.6	105	40.6	141	60.6	177	80.6
−39	−39.4	−2	−18.9	34	1.1	70	21.1	106	41.1	142	61.1	178	81.1
−38	−38.9	−1	−18.3	35	1.7	71	21.7	107	41.7	143	61.7	179	81.7
−37	−38.3	0	−17.8	36	2.2	72	22.2	108	42.2	144	62.2	180	82.2
−36	−37.8	+1	−17.2	37	2.8	73	22.8	109	42.8	145	62.8	181	82.8
−35	−37.2	2	−16.7	38	3.3	74	23.3	110	43.3	146	63.3	182	83.3
−34	−36.7	3	−16.1	39	3.9	75	23.9	111	43.9	147	63.9	183	83.9
−33	−36.1	4	−15.6	40	4.4	76	24.4	112	44.4	148	64.4	184	84.4
−32	−35.6	5	−15	41	5	77	25	113	45	149	65	185	85
−31	−35	6	−14.4	42	5.6	78	25.6	114	45.6	150	65.6	186	85.6
−30	−34.4	7	−13.9	43	6.1	79	26.1	115	46.1	151	66.1	187	86.1
−29	−33.9	8	−13.3	44	6.7	80	26.7	116	46.7	152	66.7	188	86.7
−28	−33.3	9	−12.8	45	7.2	81	27.2	117	47.2	153	67.2	189	87.2
−27	−32.8	10	−12.2	46	7.8	82	27.8	118	47.8	154	67.8	190	87.8
−26	−32.2	11	−11.7	47	8.3	83	28.3	119	48.3	155	68.3	191	88.3
−25	−31.7	12	−11.1	48	8.9	84	28.9	120	48.9	156	68.9	192	88.9
−24	−31.1	13	−10.6	49	9.4	85	29.4	121	49.4	157	69.4	193	89.4
−23	−30.6	14	−10	50	10	86	30	122	50	158	70	194	90
−22	−30	15	− 9.4	51	10.6	87	30.6	123	50.6	159	70.6	195	90.6
−21	−29.4	16	− 8.9	52	11.1	88	31.1	124	51.1	160	71.1	196	91.1
−20	−28.9	17	− 8.3	53	11.7	89	31.7	125	51.7	161	71.7	197	91.7
−19	−28.3	18	− 7.8	54	12.2	90	32.2	126	52.2	162	72.2	198	92.2
−18	−27.8	19	− 7.2	55	12.8	91	32.8	127	52.8	163	72.8	199	92.8
−17	−27.2	20	− 6.7	56	13.3	92	33.3	128	53.3	164	73.3	200	93.3
−16	−26.7	21	− 6.1	57	13.9	93	33.9	129	53.9	165	73.9	201	93.9
−15	−26.1	22	− 5.6	58	14.4	94	34.4	130	54.4	166	74.4	202	94.4
−14	−25.6	23	− 5	59	15	95	35	131	55	167	75	203	95
−13	−25	24	− 4.4	60	15.6	96	35.6	132	55.6	168	75.6	204	95.6
−12	−24.4	25	− 3.9	61	16.1	97	36.1	133	56.1	169	76.1	205	96.1
−11	−23.9	26	− 3.3	62	16.7	98	36.7	134	56.7	170	76.7	206	96.7
−10	−23.3	27	− 2.8	63	17.2	99	37.2	135	57.2	171	77.2	207	97.2
− 9	−22.8	28	− 2.2	64	17.8	100	37.8	136	57.8	172	77.8	208	97.8
− 8	−22.2	29	− 1.7	65	18.3	101	38.3	137	58.3	173	78.3	209	98.3
− 7	−21.7	30	− 1.1	66	18.9	102	38.9	138	58.9	174	78.9	210	98.9
− 6	−21.1	31	− 0.6	67	19.4	103	39.4	139	59.4	175	79.4	211	99.4
− 5	−20.6	32	− 0	68	20	104	40	140	60	176	80	212	100
− 4	−20												

(Kent. *Mechanical Engineers' Pocket Book.*)

COMPARATIVE TABLE OF TEMPERATURES, CENTIGRADE TO FAHRENHEIT.

C	F	C	F	C	F	C	F	C	F
−40	−40	−11	12.2	17	62.6	45	113	73	163.4
−39	−38.2	−10	14	18	64.4	46	114.8	74	165.2
−38	−36.4	− 9	15.8	19	66.2	47	116.6	75	167
−37	−34.6	− 8	17.6	20	68	48	118.4	76	168.8
−36	−32.8	− 7	19.4	21	69.8	49	120.2	77	170.6
−35	−31	− 6	21.2	22	71.6	50	122	78	172.4
−34	−29.2	− 5	23	23	73.4	51	123.8	79	174.2
−33	−27.4	− 4	24.8	24	75.2	52	125.6	80	176
−32	−25.6	− 3	26.6	25	77	53	127.4	81	177.8
−31	−23.8	− 2	28.4	26	78.8	54	129.2	82	179.6
−30	−22	− 1	30.2	27	80.6	55	131	83	181.4
−29	−20.2	0	32	28	82.4	56	132.8	84	183.2
−28	−18.4	+ 1	33.8	29	84.2	57	134.6	85	185
−27	−16.6	2	35.6	30	86	58	136.4	86	186.8
−26	−14.8	3	37.4	31	87.8	59	138.2	87	188.6
−25	−13	4	39.2	32	89.6	50	140	88	190.4
−24	−11.2	5	41	33	91.4	61	141.8	89	192.2
−23	− 9.4	6	42.8	34	93.2	62	143.6	90	194
−22	− 7.6	7	44.6	35	95	63	145.4	91	195.8
−21	− 5.8	8	46.4	36	96.8	64	147.2	92	197.6
−20	− 4	9	48.2	37	98.6	65	149	93	199.4
−19	− 2.2	10	50	38	100.4	66	150.8	94	201.2
−18	− 0.4	11	51.8	39	102.2	67	152.6	95	203
−17	+ 1.4	12	53.6	40	104	68	154.4	96	204.8
−16	3.2	13	55.4	41	105.8	69	156.2	97	206.6
−15	5	14	57.2	42	107.6	70	158	98	208.4
−14	6.8	15	59	43	109.4	71	159.8	99	210.2
−13	8.6	16	60.8	44	111.2	72	161.6	100	212
−12	10.4								

To change Centigrade to Fahrenheit, divide by 5, multiply by 9, and add 32.

To change Fahrenheit to Centigrade, subtract 32, divide by 9, multiply by 5.

(Kent. *Mechanical Engineers' Pocket Book.*)

TABLE SHOWING PRESSURE PER SQUARE INCH IN POUNDS WITH VARYING HEAD OF WATER IN FEET.

Head Ft.	Pressure	Head Ft.	Pressure	Head Ft.	Pressure	Head Ft.	Pressure
1	.433	34	14.722	67	29.011	100	43.300
2	.866	35	15.155	68	29.444	105	45.465
3	1.299	36	15.588	69	29.877	110	47.630
4	1.732	37	16.021	70	30.310	115	49.795
5	2.165	38	16.454	71	30.743	120	51.960
6	2.598	39	16.887	72	31.176	125	54.125
7	3.031	40	17.320	73	31.609	130	56.290
8	3.464	41	17.753	74	32.042	135	58.455
9	3.897	42	18.186	75	32.475	140	60.620
10	4.330	43	18.619	76	32.908	145	62.785
11	4.763	44	19.052	77	33.341	150	64.950
12	5.196	45	19.485	78	33.774	155	67.115
13	5.629	46	19.918	79	34.207	160	69.280
14	6.062	47	20.351	80	34.640	165	71.445
15	6.495	48	20.784	81	35.073	170	73.610
16	6.928	49	21.217	82	35.506	175	75.775
17	7.361	50	21.650	83	35.939	180	77.940
18	7.794	51	22.083	84	36.372	185	80.105
19	8.227	52	22.516	85	36.805	190	82.270
20	8.660	53	22.949	86	37.238	195	84.435
21	9.093	54	23.382	87	37.671	200	86.600
22	9.526	55	23.815	88	38.104	225	97.425
23	9.959	56	24.248	89	38.537	250	108.250
24	10.392	57	24.681	90	38.970	275	119.075
25	10.825	58	25.114	91	39.403	300	129.900
26	11.258	59	25.547	92	39.836	325	140.725
27	11.691	60	25.890	93	40.269	350	151.550
28	12.124	61	26.413	94	40.702	375	162.375
29	12.557	62	26.846	95	41.135	400	173.200
30	12.990	63	27.279	96	41.568	425	184.025
31	13.423	64	27.712	97	42.001	450	194.850
32	13.856	65	28.145	98	42.434	475	205.675
33	14.289	66	28.578	99	42.867	500	216.500

TABLE SHOWING THE EXPANSION OF WATER AT DIFFERENT TEMPERATURES COMPARED WITH VOLUME AT GREATEST DENSITY (4° C.).

Cent.	Fahr.	Volume	Cent.	Fahr.	Volume
4°	39.1°	1.00000	55	131	1.01423
5	41	1.00001	60	140	1.01678
10	50	1.00025	65	149	1.01951
15	59	1.00083	70	158	1.02241
20	68	1.00171	75	167	1.02548
25	77	1.00286	80	176	1.02872
30	86	1.00425	85	185	1.03213
35	95	1.00586	90	194	1.03570
40	104	1.00767	95	203	1.03943
45	113	1.00967	100	212	1.04332
50	122	1.01186			

TABLE SHOWING HEAD OF WATER IN FEET WITH VARYING PRESSURE IN POUNDS PER SQUARE INCH.

Pressure	Head Ft.	Pressure	Head Ft.	Pressure	Head Ft.	Pressure	Head Ft.
1	2.3	26	59.8	51	117.3	76	174.8
2	4.6	27	62.1	52	119.6	77	177.1
3	6.9	28	64.4	53	121.9	78	179.4
4	9.2	29	66.7	54	124.2	79	181.7
5	11.5	30	69.0	55	126.5	80	184.0
6	13.8	31	71.3	56	128.8	81	186.3
7	16.1	32	73.6	57	131.1	82	188.6
8	18.4	33	75.9	58	133.4	83	190.9
9	20.7	34	78.2	59	135.7	84	193.2
10	23.0	35	80.5	60	138.0	85	195.5
11	25.3	36	82.8	61	140.3	86	197.8
12	27.6	37	85.1	62	142.6	87	200.1
13	29.9	38	87.4	63	144.9	88	202.4
14	32.2	39	89.7	64	147.2	89	204.7
15	34.5	40	92.0	65	149.5	90	207.0
16	36.8	41	94.3	66	151.8	91	209.3
17	39.1	42	96.6	67	154.1	92	211.6
18	41.4	43	98.9	68	156.4	93	213.9
19	43.7	44	101.2	69	158.7	94	216.2
20	46.0	45	103.5	70	161.0	95	218.5
21	48.3	46	105.8	71	163.3	96	220.8
22	50.6	47	108.1	72	165.6	97	223.1
23	52.9	48	110.4	73	167.9	98	225.4
24	55.2	49	112.7	74	170.2	99	227.7
25	57.5	50	115.0	75	172.5	100	230.0

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